LEVEL 1 REQUIREMENTS

FOR THE

GEOSPACE-RADIATION BELT STORM PROBES

MISSION IN THE

GEOSPACE MISSIONS PROJECT

Appendix C

to the

Living With a Star Program Plan

May 11, 2007

Draft for

Mission Design Review

Appendix C

Level 1 Requirements for the Geospace-Radiation Belt Storm Probes Mission in the Geospace Missions Project

1.0 INTRODUCTION

1.1 SCOPE

This appendix to the Living With a Star (LWS) Program Plan defines the Level 1 requirements for the development and operation of the Geospace-Radiation Belt Storm Probes (G-RBSP) mission in the Geospace Missions (GM) project. The GM project is a research spacecraft project, part of the science missions segment of the LWS program. The specific requirements are presented in Section 2.0.

This document serves as the basis for project assessments conducted by NASA Headquarters during the G-RBSP mission development period and provides the baseline for the determination of the science mission success following the completion of the operational phase. Changes to information and requirements contained in this document require approval by the Associate Administrator for the Science Mission Directorate (SMD) at NASA Headquarters.

The G-RBSP mission makes measurements from two spacecraft traveling in low-inclination elliptical lapping orbits around the Earth to quantify proposed mechanisms for energetic particle acceleration, transport, and loss in space environments. The mission's in situ probes will provide access to and detailed observations of the full range of processes associated with the highly energetic particles that operate within the inner magnetosphere. The energetic particles of interest are electrons and the hydrogen (or protons, H^+), helium (He^+) and oxygen (O^+) ions with relativistic and sub-relativistic energies. The G-RBSP mission will measure their distributions as functions of energy, location, and velocity; measurements of electric and magnetic fields will be essential in understanding the distributions and their variability. The most prominent variations in the distributions of energetic particles occur during geomagnetic disturbances driven by fluctuations in the Sun and its solar wind that interact with the Earth's magnetic and electric fields. Source or "seed" populations for the radiation belts include both the particles emitted from the Sun and pre-existing populations of thermal and supra-thermal particles within the magnetosphere. Variations in the electric and magnetic fields accelerate and transport the seed populations to form or enhance the radiation belts.

The two-year prime mission lifetime will provide sufficient local time, altitude, and event coverage to determine the relative significance of the various proposed mechanisms that operate within the radiation belts and their interaction modes. New physics-based and empirical models for the Earth's radiation belt environment that are important for engineering applications will result from this mission.

1.2 STRATEGIC IMPORTANCE

The relationships of the LWS program to the strategic goals, science goals, and research objectives for the heliophysics science theme in the SMD and to the *2006 NASA Strategic Plan*[1] are described in paragraph 2.0 of the LWS Program Plan.

The G-RBSP mission addresses these requirements in two ways, by performing science investigations alone, and by participating with other heliophysics missions in performing system investigations of the Sun's activity and the Earth's space environment response. As a stand-alone mission, the G-RBSP mission is a major contributor to all three heliophysics research objectives in the *Science Plan for NASA's Science Mission Directorate 2007-2016*[2] that flow from sub-goal 3b in the *2006 NASA Strategic Plan*[1] and down to the heliophysics roadmap[3], a reference document. These relationships are shown in Table 1.2-1. The system investigations depend upon the availability, locations, and accuracy of other heliophysics missions and are not under the control of the G-RBSP mission. Since the G-RBSP mission cannot control the availability of data from other heliophysics missions, the G-RBSP mission Level I requirements address only the G-RBSP investigations that are under the control of the G-RBSP mission.

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1. Anon., 2006 NASA Strategic Plan, Doc. No. NP-2006-02-423-HQ. NASA Headquarters, Washington, DC, Feb. 2006.

2. Anon., Science Plan for NASA's Science Mission Directorate 2007-2016, Doc. No. NP-2007-03-461-HQ. NASA Headquarters, Washington, DC, Jan. 2007.

3. Anon., Heliophysics, The New Science of the Sun-Solar System Connection: Recommended Roadmap for Science and Technology 2005-2035, Doc. No. NP-2005-11-740-GSFC. NASA Goddard Space Flight Center, Greenbelt, MD, Feb. 2006.

NASA Strategic Goal 3: Develop a balanced overall program of science, exploration, and aeronautics consistent with the redirection of the human spaceflight program to focus on exploration.	
NASA Strategic Sub-goal 3B and Heliophysics Science Goal: Understand the Sun and its effects on Earth and the solar system.	
Research Objectives for Heliophysics Science Goal	**Applicability of the G-RBSP Mission to the Heliophysics Research Objectives**
Understand the fundamental physical processes of the space environment from the Sun to Earth, to other planets, and beyond to the interstellar medium	Major Contributor
Understand how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields	Major Contributor
Maximize the safety and productivity of human and robotic explorers by developing the capability to predict the extreme and dynamic conditions in space	Major Contributor

Table 1.2-1. Relationship of the G-RBSP mission to the *2006 NASA Strategic Plan*[1], the heliophysics science goals, and the heliophysics research objectives.

1.3 SCIENTIFIC GOALS, INSTRUMENT SCIENCE OBJECTIVES AND MEASUREMENT OBJECTIVES

The goal of the G-RBSP mission is to provide understanding, ideally to the point of predictability, of how populations of relativistic electrons and ions in space form or change in response to variable inputs of energy from the Sun. The G-RBSP mission will achieve this goal by identifying and quantifying the processes that cause the acceleration, global distribution, and variability of relativistic electrons and ions in the inner magnetosphere

The science objectives for the G-RBSP mission are to improve the scientific understanding in eight research areas as follows:

- Identify the processes responsible for the acceleration and transport of relativistic and near-relativistic particles, determine when and where these processes occur, and determine their relative significance;

- Identify the processes responsible for the precipitation and loss of relativistic and near relativistic particles, determine when and where these processes occur, and determine their relative significance;

- Quantify the processes that lead to the formation and subsequent decay of transient radiation belt structures;

- Quantify the relative contribution of adiabatic and non-adiabatic processes on the acceleration, transport, and loss of energetic particles;

- Determine the role of "seed" or source populations for relativistic particle events;

- Quantify the effects of the ring current and related storm phenomena on relativistic particles;

- Quantify how and why the ring current and associated phenomena vary during storms; and,

- Use the science understanding to improve and validate physics-based data assimilation and specification models for the Earth's radiation belts.

The measurement objectives for the G-RBSP mission are defined as follows:

- Measure relativistic and near-relativistic particles within the Earth's radiation belts as functions of energy, angle, and elemental composition (electrons, H^+, He^+, and O^+);

- Measure the particles that comprise the Earth's ring current (whose pressure alters the electric and magnetic field configuration of the inner magnetosphere) as functions of energy, angle, and elemental composition;

- Measure the source population of thermal and supra-thermal particles that can also generate waves within the Earth's radiation belts as functions of energy, angle, and elemental composition;

- Measure the magnetic field that orders particle distributions and helps to determine the configuration of and variations in the inner magnetosphere;

- Measure the electric field that energizes particles and determines the large spatial-scale configuration of and variations in plasma flows within the inner magnetosphere;

- Measure the electric and magnetic field components of plasma waves and transients that are important for understanding interactions with charged particles;

- Measure the particle, magnetic field, electric field, and wave parameters at two positions within the Earth's radiation belts to determine radial profiles, simultaneously observe source and resulting populations, and separate spatial and temporal effects; and,

- Measure the particle, magnetic field, electric field, and wave parameters for extended time periods to characterize the processes that affect relativistic and near-relativistic particles over a wide range of conditions.

1.4 PROJECT ORGANIZATION AND MANAGEMENT

The Office of Space Science at NASA Headquarters designated the Goddard Space Flight Center (GSFC) as the NASA Lead Center for the LWS program on July 13, 2000. As Lead Center, GSFC has primary responsibility for managing the implementation of the LWS program and its associated projects. The SMD at NASA Headquarters assigned the Johns Hopkins University/Applied Physics Lab (JHU/APL) the responsibility for mission management, design, integration, and operation of the G-RBSP mission in compliance with NASA Procedure and Requirements (NPR) 7120.5D and the LWS Program Plan. The JHU/APL mission scientist will provide the science interface between the investigation providers and the JHU/APL project office for phases A through D. The GSFC project scientist will provide the science interface with the science community and will manage the Phase E science activities.

The Governing Program Management Council (PMC) for the LWS program is the SMD PMC. The G-RBSP mission is a Category 2 mission, and its Governing PMC is also the SMD PMC.

1.4.1 TEAMING ARRANGEMENTS

The primary teaming arrangements for the G-RBSP mission implementation and flight operations are between the GSFC, JHU/APL, universities, and the National Reconnaissance Office (NRO). The universities were selected for instrument investigations from the G-RBSP Announcement of Opportunity (AO) and are under contract to the JHU/APL. The NRO is providing an investigation that includes an instrument through a partnering agreement with NASA. The JHU/APL is under contract to NASA, and the Contracting Officer's Technical Representative (COTR) resides in the LWS program office at the GSFC. The instrument providers are the key contributors to the scientific success of the G-RBSP mission. Each organization will provide two identical sets of instrumentation, one for each G-RBSP spacecraft. They have the following investigation responsibilities:

- Boston University –Energetic Particle, Composition, and Thermal Plasma (ECT) Instrument Suite;

- University of Iowa – Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS);

- University of Minnesota - Electric Field and Waves Instrument (EFW);

- New Jersey Institute of Technology – Radiation Belt Storm Probes Ion Composition Experiment (RB-SPICE); and,

- NRO – Proton Spectrometer Belt Research (PSBR).

1.4.2 PROJECT ACQUISITION STRATEGY

The JHU/APL will design, develop, integrate, test, and operate the G-RBSP observatories and G-RBSP ground system. The acquisition of sub-contracted spacecraft sub-assemblies, components, and parts will be through contracts issued by the JHU/APL procurement office. NASA will fund the JHU/APL through tasks issued against the sole source, Headquarters-held contract for the LWS program. The LWS program office at GSFC will serve as the COTR for the G-RBSP tasks and, in that capacity, oversee the task orders that authorize and fund the G-RBSP mission.

The ECT, EMFISIS, EFW, and RB-SPICE science investigations were procured through the AO process; their formulation, development and operations will be funded by contracts with the JHU/APL, and their data analyses will be funded by contracts or grants with GSFC. The PSBR science investigation is being acquired through a Memorandum of Agreement between NASA and the NRO. The NRO will fund the development, science operations, and data analysis for the PSBR investigation. NASA will fund the JHU/APL to accommodate and operate the instruments from the PSBR investigation, the Relativistic Proton Spectrometer (RPS), as government-furnished equipment.

The Kennedy Space Center launch services contract will be used to acquire the launch vehicle.

2.0 PROGRAMMATIC REQUIREMENTS

2.1 SCIENCE REQUIREMENTS TO ACHIEVE FULL MISSION SUCCESS

The science requirements for the G-RBSP mission to achieve full mission success are described below.

In the following sections energy resolution is defined as the accuracy with which the energy of a given particle can be measured. The polar angle is the angle relative to the spacecraft spin axis. The azimuthal angle is the angle in the spin plane. The spin plane is the plane perpendicular to the spacecraft spin axis that contains the geometric center of the spacecraft.

Wave parameters characterize wave variations as functions of time and frequency and are a compact way to summarize many important characteristics of observed wave modes, using minimal telemetry. The parameters include wave energy, polarization, coherence, wave normal angle, phase velocity, and wave number. The sensitivity is defined as the amplitude of the weakest signal that can be detected. The dynamic range is defined as the ratio of the amplitude of the largest signal that can be measured in decibels (dB) to the amplitude of the weakest signal that can be measured. Waveforms are the digitized records of the electric or magnetic field variations as a function of time.

2.1.1 ECT INSTRUMENT PERFORMANCE REQUIREMENTS

The ECT instrument suite will provide data to improve understanding of particle acceleration mechanisms, relativistic and near-relativistic particle enhancement and loss, and how the near-Earth environment controls those acceleration and loss processes. Each ECT instrument suite measures electrons and ions as functions of energy and angle. Spacecraft rotation about an axis nearly perpendicular to the magnetic field permits sampling over a full range of look-angle directions in either two or three dimensions.

Each ECT instrument suite contains three types of instruments as follows:

- The Helium Oxygen Proton Electron (HOPE) spectrometer is an electrostatic analyzer and a time-of-flight mass spectrometer that measures low-energy electrons and ions as a function of energy angle, and ion species (H^+, He^+, O^+);
- Magnetic Electron Ion Spectrometer (MagEIS) is a set of four energetic particle magnetic spectrometers that measure high-energy electrons and ions over three different energy ranges and either one or two different directions (depending on energy range) relative to the spacecraft spin axis; and,
- The Relativistic Electron Proton Telescope (REPT) is a particle telescope that measures very high-energy electrons and protons in one direction relative to the spacecraft spin axis.

2.1.1.1 Each HOPE instrument shall measure the distribution of electron and ion fluxes by composition at a cadence of once every two spin periods with five detectors, each with a 20-degree polar angle width and an azimuthal resolution of at least eight sectors per spin as follows:

2.1.1.1.1 Electrons over the energy range from either 20 electron Volts (eV) or spacecraft potential, whichever is greater, to 45 kilo-electron Volts (keV), with an energy resolution of 20 percent or better.

2.1.1.1.2 Proton fluxes over the energy range from either 20 eV or spacecraft potential, whichever is greater, to 45 keV, with an energy resolution of 20 percent or better.

2.1.1.1.3 Helium (He^+) and oxygen (O^+) fluxes over the energy range from either 20 eV or spacecraft potential, whichever is greater, to 45 keV, with an energy resolution of 20 percent or better.

2.1.1.2 Each MagEIS shall measure the distribution of electrons and ions by composition at a cadence of once every two spin periods with four detectors of 20-degree polar angle width each and with azimuthal resolution of at least eight sectors per spin as follows:

2.1.1.2.1 Electron fluxes over the energy range from 45 keV to 4 Mega-electron Volts (MeV) with an energy resolution of 30 percent or better.

2.1.1.2.2 Proton fluxes over the energy range from 20 keV to 10 MeV with an energy resolution of 20 percent or better at 20 keV to 100 percent or better at 10 MeV.

2.1.1.2.3 Helium (He^+) and oxygen (O^+) fluxes (independent of charge state) over the energy range from 1 MeV per nucleon to 50 MeV per nucleon with an energy resolution of 50 percent or better at 1 MeV per nucleon to 100 percent or better at 50 MeV per nucleon.

2.1.1.3 Each REPT shall measure the distribution of electrons and protons at a cadence of once every minute with one detector of 30-degree polar angle width and with azimuthal resolution of at least eight sectors per spin as follows:

2.1.1.3.1 Electron fluxes over the energy range from 4 MeV to 10 MeV with an energy resolution of 30 percent or better at 4 MeV to 100 percent or better at 10 MeV.

2.1.1.3.2 Proton fluxes over the energy range from 5 MeV to 75 MeV with an energy resolution of 40 percent or better at 5 MeV to 100 percent or better at 75 MeV.

2.1.2 EMFISIS INSTRUMENT PERFORMANCE REQUIREMENTS

The EMFISIS instrument suite will improve the understanding of the origin and role of plasma waves in particle acceleration and loss and in the evolution of the magnetic field. The plasma waves and magnetic field control and respond to the motion of charged particles and to variations in the structures of the particle populations in space, as exemplified by the radiation belts, the plasmasphere, and the ring current in near Earth space. Each EMFISIS instrument suite contains two types of instruments as follows:

- A low-frequency magnetometer (MAG) that measures the three components of the low-frequency magnetic field; and,
- A high-frequency magnetometer and waveform receivers (Waves) that measure the three components of the high-frequency wave magnetic and wave electric fields.

2.1.2.1 Each MAG shall measure the low-frequency magnetic field in three orthogonal directions over a frequency range from quasi-static (DC) to 15 Hertz (Hz) at a cadence of 32 vectors per second and a range of magnetic field strengths from zero to 32000 nanoTesla (nT) with an accuracy of 5 nT and a precision ranging from 0.1 nT at 4000 nT to 2 nT at 32000 nT.

2.1.2.2 Each Waves shall measure high-frequency magnetic field variations in three orthogonal directions from 10 Hz to 12 kiloHertz (kHz), producing wave parameters once every six seconds and waveforms when the spacecraft is within 2500 kilometers (km) of the geomagnetic equator for 30 minutes every three orbits over a magnitude range of 90 dB with an accuracy of 1 dB, and sensitivity of at least 3 $\times 10^{-11}$ nT^2/Hz at 1 kHz.

2.1.2.3 Each Waves shall measure low-frequency electric field variations in three orthogonal directions from 10 Hz to 12 kHz, producing wave parameters once every 6 seconds and waveforms when the spacecraft is within 2500 km of the geomagnetic equator for 30 minutes every three orbits over a magnitude range of 110 dB, an accuracy of 1 dB, and a sensitivity of at least 3×10^{-17} square Volts per square meter-Hz (V^2/m^2-Hz) at 1 kHz.

2.1.2.4 Each Waves shall measure a one-dimensional high-frequency electric field spectrum once every 6 seconds over the frequency range from 10 Hz to 400 kHz, with a magnitude range of 90 dB, an accuracy of 1 dB, and a sensitivity of 3×10^{-18} V^2/m^2-Hz at 100 kHz.

2.1.3 EFW INSTRUMENT PERFORMANCE REQUIREMENTS

The EFW investigation will improve the understanding of the electric fields associated with particle energization, scattering, transport, and the large-scale convection that modifies the structure of the inner magnetosphere.

The EFW instrument is comprised of three electric field sensor pairs on three paired boom sets. Two pairs measure the two-dimensional electric field in the plane normal to the spacecraft spin axis, and one pair measures the electric field component along the spacecraft spin axis.

2.1.3.1 Each pair of EFW axial (i.e., spin-aligned) booms shall measure the steady and low-frequency DC to 200 Hz electric fields with magnitudes ranging from 2 milliVolts per meter (mV/m) to plus or minus 300 mV/m with a precision of 0.05 mV/m and a sensitivity of at least 2 mV/m or 10 percent of the total field, whichever is greater, when the measurement is taken above 2.5 Earth Radii (R_E).

2.1.3.2 Each set of EFW spin-plane booms shall measure the steady and low-frequency DC to 200 Hz electric field components perpendicular to the observatory spin axis with magnitudes ranging from 0 to 300 mV/m, with a precision of 0.05 mV/m, and a sensitivity of at least 0.3 mV/m or 10 percent of the total field, whichever is greater, when the measurements are taken above 2.5 R_E.

2.1.3.3 Each EFW shall measure variations in the spacecraft electric potential relative to the plasma potential at a maximum cadence of one hundred samples per second over a magnitude range corresponding to densities (n) ranging from 0.1 to 50 per cubic centimeter (cm^{-3}) with an error in the magnitude of the densities that does not exceed 50 percent when electron temperatures are below 30 eV.

2.1.3.4 Each EFW set of spin plane booms shall measure high frequency (AC) electric field wave parameters at a frequency range of 10 Hz to 2 kHz once every six seconds over a magnitude range of 80 dB and a sensitivity of 10^{-13} V^2/m^2-Hz at 1 kHz.

2.1.3.5 The EFW instrument shall measure the signals from each of the six electric field sensors at a maximum rate of 15 kHz to provide measurements of the propagation velocity, direction, and scale size of waves propagating over the spacecraft.

2.1.3.6 Each EFW shall measure low frequency AC magnetic field wave parameters at a frequency range of 10 Hz to 200 Hz once every 6 seconds over a magnitude range of 90 dB, with a sensitivity of 3×10^{-11} nT^2/Hz at 1 kHz, an accuracy of 1 dB, including waveforms for periods up to 1800 minutes per week.

2.1.4 RB-SPICE INSTRUMENT PERFORMANCE REQUIREMENTS

The RB-SPICE instrument will provide data to determine the spatial distribution of ring current pressures needed to understand how the inner magnetosphere changes during storm times and determine how variations in the magnetic field and plasma waves related to the ring current control particle acceleration and loss.

Each RB-SPICE instrument is a time-of-flight versus energy spectrometer that measures medium energy H^+, He^+, and O^+ ions as functions of energy and angle. Spacecraft rotation permits sampling over the full range of look directions in three dimensions.

2.1.4.1 Each RB-SPICE shall measure ion distributions by composition once every spin period with angular resolutions of 30 degrees or better as follows.

2.1.4.1.1 Proton fluxes over the energy range from 45 keV to 400 keV with an energy resolution of 20 percent.

2.1.4.1.2 Helium (He^+) fluxes over the energy range from 45keV to 400 keV with an energy resolution of 40 percent.

2.1.4.1.3 Oxygen (O^+) fluxes over the energy range from 45 keV to 400 keV with an energy resolution of 40 percent.

2.1.5 RPS INSTRUMENT PERFORMANCE REQUIREMENTS

The RPS instrument measures proton fluxes in the magnetosphere. Its observations will be used to develop and validate models for the inner radiation belts.

2.1.5.1 The NRO shall deliver two fully-qualified RPS instruments and an acceptance data package to NASA.

2.1.5.2 Each RPS shall measure proton spectra and pitch angle distributions once per minute over the energy range from 100 MeV to 1 Giga-electron Volts (GeV) with an energy resolution of 50 percent at 100 MeV to 100 percent at 1 GeV and an angular resolution of 10 degree or better.

2.1.6 FULL MISSION SUCCESS CRITERIA

Each G-RBSP spacecraft shall obtain data from all five instruments using the instrument performance requirements for full mission success as defined in paragraphs 2.1.1 through 2.1.5. At least one G-RBSP spacecraft shall operate for two years and both G-RBSP spacecraft shall operate concurrently for at least 12 months after commissioning.

2.2 SCIENCE REQUIREMENTS TO ACHIEVE MINIMUM SUCCESS

The science requirements for the G-RBSP mission to achieve minimum mission success are described below.

2.2.1 ECT INSTRUMENT PERFORMANCE REQUIREMENTS

2.2.1.1 Each MagEIS shall measure the distribution of electrons and ions by composition at a cadence of once every two spin periods with four detectors of 20-degree polar angle width each and with azimuthal resolution of at least eight sectors per spin as follows:

2.2.1.1.1 Electron fluxes over the energy range from 45 keV to 4 MeV with an energy resolution of 30 percent or better.

2.2.2 EMFISIS INSTRUMENT PERFORMANCE REQUIREMENTS

2.2.2.1 Each MAG shall measure the low-frequency magnetic field in three orthogonal directions over a frequency range from DC to 15 Hz at a cadence of 32 vectors per second and a range of magnetic field strengths from zero to 32000 nanoTesla (nT) with an accuracy of 5 nT and a precision ranging from 0.1 nT at 4000 nT to 2 nT at 32000 nT.

2.2.2.2 One Waves on one spacecraft shall measure high-frequency magnetic field variations in three orthogonal directions from 10 Hz to 12 kHz, producing wave parameters once every six seconds over a magnitude range of 90 dB with an accuracy of 1 dB and a sensitivity of at least 3×10^{-11} nT^2/Hz at 1 kHz.

2.2.2.3 Each Waves shall measure low-frequency electric field variations in two orthogonal directions from 10 Hz to 12 kHz, producing wave parameters once every 6 seconds over a magnitude range of 110 dB with an accuracy of 1 dB and a sensitivity of at least 3×10^{-17} V^2/m^2-Hz at 1 kHz.

2.2.3 EFW INSTRUMENT PERFORMANCE REQUIREMENTS

2.2.3.1 Two pairs of EFW spin-plane booms on one spacecraft shall measure the steady and low-frequency DC to 15 Hz electric fields components perpendicular to the observatory spin axis with magnitudes ranging from 0 to 300 mV/m, a cadence of 32 vectors per second, a precision of 0.05 mV/m, and a sensitivity of at least 0.3 mV/m or 10 percent of the total field, whichever is greater, when the measurement is taken above 2.5 R_E.

2.2.3.2 Two pairs of EFW spin-plane booms on one spacecraft shall measure variations in the spacecraft electric potential relative to the plasma potential at a cadence of at least one sample per second over a magnitude range corresponding to densities ranging from 0.1 to 50 cm^{-3} with an error in the magnitude of the densities that does not exceed 50 percent when electron temperatures are below 30 eV.

2.2.4 RB-SPICE INSTRUMENT PERFORMANCE REQUIREMENTS

2.2.4.1 Each RB-SPICE shall measure ion distributions by composition once every spin period with angular resolutions of 30 degrees or better as follows.

2.2.4.1.1 Protons fluxes over the energy range from 45 keV to 400 keV with an energy resolution of 20 percent.

2.2.4.1.3 Oxygen (O^+) fluxes over the energy range from 45 keV to 400 keV with an energy resolution of 40 percent.

2.2.5 RPS INSTRUMENT PERFORMANCE REQUIREMENTS

2.2.5.1 Each RPS shall measure proton energies once per minute over the energy range from 100 MeV to 1 GeV with an energy resolution of 50 percent at 100 MeV to 100 percent at 1 GeV and an angular resolution of 20 degrees or better.

2.2.6 MINIMUM MISSION SUCCESS CRITERIA

2.2.6.1 Each G-RBSP spacecraft shall obtain data from all five instruments on the spacecraft using the instrument performance requirements for minimum mission success as defined in paragraphs 2.2.1 through 2.2.5. At least one G-RBSP spacecraft shall operate for 12 months, and both G-RBSP spacecraft shall operate concurrently for at least nine months after commissioning.

2.3 MISSION AND SPACECRAFT PERFORMANCE REQUIREMENTS

2.3.1 The design lifetime for each G-RBSP spacecraft shall be two years following a 45-day commissioning period after launch and independent of the launch date.

2.3.2 The G-RBSP mission shall contain two identical Sun-pointing spin-stabilized spacecraft.

2.3.3 The off-pointing angle between the spin axis of each spacecraft and the ecliptic plane shall not exceed 20 degrees in the north-south direction, and the off-pointing angle between the spin axis of each spacecraft and the Sun-spacecraft line shall not exceed 25 degrees in the east-west direction.

2.3.4 Each G-RBSP spacecraft shall be designed to operate in an orbit with a nominal perigee that is no lower than 600 km, a nominal apogee of 5.8 R_E geocentric altitude (or an altitude of 30,615 km) plus or minus 300 km, and an orbital inclination that is 10 degrees plus or minus one degree, and independent of the launch date.

2.3.5 The G-RBSP-supplied propulsion system shall have the capability to modify the orbit of each G-RBSP spacecraft to achieve its operational science orbits as defined in paragraph 2.3.4.

2.3.6 The two G-RBSP spacecraft shall have the capability to be available for concurrent science measurements and operations at least 95 percent of the prime mission lifetime.

2.3.7 The two G-RBSP spacecraft shall make concurrent measurements while operating in nearly identical orbits in which the spacecraft lap each other at least twice while the apogee resides within each local time quadrant.

2.3.8 In accordance with the Formulation Authorization Document for the G-RBSP mission, the G-RBSP mission shall be designed in accordance with Risk Category C missions as defined in NPR 8705.4.

2.3.9 Each G-RBSP spacecraft shall be launched containing propellant nominally sufficient to support extended science operations for 24 months.

2.3.10 The end-to-end system of the G-RBSP instruments, spacecraft, and ground system shall have the capability to meet full mission success as defined in paragraph 2.1.6.

2.3.11 The wet mass of the G-RBSP payload to be integrated on the Evolved Expendable Launch Vehicle (EELV) including all spacecraft and launch vehicle interface hardware shall not exceed 1500 kilograms.

2.3.12 The G-RBSP mission shall be designed to operate nominally using staffed operations for eight hours per day and five days per week.

2.3.13 The G-RBSP mission shall provide data from each spacecraft to the Science Operations Centers (SOC) with an end-to-end error rate that does not exceed five percent as measured on a monthly basis.

2.3.14 Each G-RBSP spacecraft shall be designed to broadcast real-time space weather data at a rate no larger than 50 bits per second (bps).

2.3.15 The G-RBSP prime mission funding shall provide for funding for science data analysis for the prime mission lifetime and one additional year after completion of the prime mission.

2.3.16 Each G-RBSP spacecraft shall be designed to support uncontrolled end-of-life disposal to limit orbital debris per NASA-STD-8719.14.

2.4 LAUNCH VEHICLE REQUIREMENTS

2.4.1 The G-RBSP payload shall be launched on an EELV capable of delivering the G-RBSP payload (including two spacecraft, the interface adapter for the two spacecraft, and the launch vehicle interface hardware) to the nominal operational orbit defined in section 2.3.4.

2.4.2 The EELV shall provide for the orbital insertion of each G-RBSP spacecraft into its operational orbit as defined in paragraph 2.3.4 at a power-positive Sun-pointing attitude and with an initial spin-up of each G-RBSP spacecraft.

2.4.3 The EELV shall provide mechanical and electrical interfaces to the G-RBSP payload and the ground system for testing, verification, and flight operations.

2.5 GROUND SYSTEM REQUIREMENTS

2.5.1 All mission- and time-critical activities shall be performed within ground contact to allow for telemetry monitoring and real-time commanding.

2.5.2 The ground system shall support achieving the mission and spacecraft performance requirements as defined in paragraphs 2.1 and 2.3 in the absence of G-RBSP-provided funding to upgrade the antennas at the JHU/APL.

2.5.3 On a monthly basis, the G-RBSP ground system shall support an average onboard science data collection rate of 100 kilobits per second (kbps) per spacecraft to support the achievement of full mission success as defined in paragraph 2.1.

2.5.4 The G-RBSP ground system shall nominally route all received G-RBSP science data to the JHU/APL Mission Operations Center no later than twenty- four hours after receiving the data.

2.5.5 The G-RBSP ground system shall provide science data and associated telemetry to the Science Operations Center (SOC) with a delay of no more than seven days after the data was measured including the capability to provide temporary storage of the data, verify receipt of the data by the SOC, and re-transmit the data to the SOC.

2.5.6 The absolute timing error in the science data between the two G-RBSP spacecraft shall not exceed plus or minus 100 milliseconds.

2.6 MISSION DATA REQUIREMENTS

2.6.1 Each science investigation team shall maintain a data archive of its instrument science, documentation, software, and science data products for the life of the prime mission.

2.6.2 Each science investigation shall provide the data obtained as part of the G-RBSP mission, including the engineering data and ancillary information and analysis software necessary to validate and calibrate the science data, to the public within two months after collection following the completion of post-launch checkout of the G-RBSP spacecraft and its instruments after launch.

2.6.3 Each science investigation team shall deliver the data archive from the prime mission to a NASA-designated location for a deep data archive within one year of the completion of the prime mission operations.

2.6.4 Each G-RBSP mission science investigation team shall perform scientific analyses required for the science goals of the G-RBSP mission as defined in paragraph 1.3.

2.6.5 Each G-RBSP mission science investigation team shall support the system investigations of the LWS Program as defined in paragraph 2.0 of the LWS Program Plan and paragraph 1.2 of this appendix, maintaining liaison with the LWS Project Scientists at meetings discussing the implementation of the plan**.**

2.7 SCHEDULE REQUIREMENTS

The G-RBSP mission shall be ready to launch no later than March 2012. Major milestones for the G-RBSP mission that occur prior to launch shall be defined in the LWS Program Commitment Agreement that is held under Headquarters control and updated yearly.

2.8 COST REQUIREMENTS

The G-RBSP mission shall be cost capped at $665 million in full cost accounting for the total life cycle cost (LCC) including the launch vehicle, two years of operations, and three years of science data analysis. Provided that Program-Level Requirements are preserved and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the G-RBSP mission shall pursue scope reduction and risk management as means to control direct costs used by the mission. The G-RBSP Project Plan shall include potential scope reductions and the time frame in which they could be implemented. If other methods of cost containment are not practical, the reductions identified in the Project Plan may be exercised. However, the Heliophysics Director at NASA Headquarters shall approve any reduction in scientific capability, including those reductions specifically identified in the Project Plan, before they are implemented by the G-RBSP Project Office or the G-RBSP mission.

3.0 EXTERNAL AGREEMENTS AND DEPENDENCIES

The G-RBSP mission has a Memorandum of Agreement with the NRO to design, fabricate, and deliver two RPS instruments as GFE, provide for the verification of RPS performance requirements, and to provide data and data analysis to NASA from the RPS instruments.

The G-RBSP mission has a Letter of Agreement (To Be Completed) with Charles University in Prague, Czech Republic, for software to support the EMFISIS investigation.

The G-RBSP mission depends upon receiving S-band radio frequency authorization (RFA) for the spacecraft granted by the National Telecommunications and Information Administration (NTIA) in the U.S. Department of Commerce. This authorization will be documented in a letter from the NTIA.

The G-RBSP mission depends upon the receiving S-band RFA for the G-RBSP ground stations to transmit that is granted by the NTIA. This authorization will be documented in a letter from the NTIA.

The RBSP mission depends upon the Consultative Committee for Space Data Systems (CCSDS) World Data Center for Satellite Information to obtain a CCSDS spacecraft identification for the G-RBSP mission. The spacecraft identification will be documented in the Global Spacecraft Identification (GSCID) Assignment Request Form.

4.0 INTERNAL AGREEMENTS AND DEPENDENCIES

The G-RBSP mission shall be conducted in consideration of the non-LWS NASA dependencies as follows.

The NASA Space Operations Mission Directorate (SOMD) will manage the procurement of the launch vehicle and launch services.

The G-RBSP shall develop a Program Service Level Agreement (PSLA) with the NASA SOMD Network Interface Management Office for tracking, communications and navigation support.

The G-RBSP mission will utilize independent software verification and validation, and the agreement for this function will be documented.

5.0 EDUCATION AND PUBLIC OUTREACH

The G-RBSP Project shall develop and execute an Education and Public Outreach Plan that is consistent with the information provided in the approved Solar Terrestrial Probes-LWS Education and Public Outreach Plan, a document that is subordinate to the LWS Program Plan.

6.0 TAILORING

No tailoring of the requirements in the LWS Program Commitment Agreement or the LWS Program Plan is planned.

Program-Level Requirements for the Geospace-Radiation Belt Storm Probes Mission

APPROVALS

NASA Headquarters:

S. Alan Stern Associate Administrator for the Science Mission Directorate	Date

NASA Goddard Space Flight Center:

Edward J. Weiler Director Goddard Space Flight Center	Date
Mary S. DiJoseph LWS Program Manager Goddard Space Flight Center	Date

Program-Level Requirements for the Geospace-Radiation Belt Storm Probes Mission

CONCURRENCES

NASA Headquarters:

Richard R. Fisher Director, Heliophysics Division	Date
Todd A. May Deputy Associate Administrator for Flight Programs	Date
Dana A. Brewer Program Executive, LWS Program	Date
Madhulika Guhathakurta Program Scientist, LWS Program	Date
Barbara Giles Program Scientist, G-RBSP Mission	Date

Program-Level Requirements for the Geospace-Radiation Belt Storm Probes Mission

CONCURRENCES (Continued)

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Program-Level Requirements for the Geospace-Radiation Belt Storm Probes Mission

CONCURRENCES (Continued)

Johns Hopkins University-Applied Physics Laboratory:

Edward Reynolds G-RBSP Project Manager Johns Hopkins University/Applied Physics Laboratory	Date